

Physics Opportunities at the Next Generation of Precision Flavor Physics

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Abstract

Starting with next-generation experiments, flavor physics fully enters the era of precision measurements. The focus shifts from testing the Standard Model to finding and characterizing new physics contributions. We review the opportunities offered by future flavor experiments, discussing the expected sensitivities of the most important measurements. We also present some examples of measurable deviations from the Standard Model in the flavor sector generated in a selection of new physics models, demonstrating the major contribution that precision flavor physics could give to the effort of going beyond the Standard Model.

1 Introduction

Up to now the Standard Model (SM) managed to pass all the experimental challenges unscathed, providing an overall good description of particle physics up to the energy scales probed in experiments so far, namely hundreds of GeV. The Higgs boson, the last missing building block of the SM, is being searched for at the LHC experiments ATLAS and CMS, which will be able to find or exclude it.

In spite of the phenomenological success, however, the SM is not satisfactory for several theoretical reasons, including the instability of the fundamental scale of weak interactions, the Fermi scale, against radiative corrections, the absence of a dark matter candidate, an amount of CP violation too small to account for the matter-antimatter asymmetry in the universe, the lack of an explanation for the origin of flavor and CP violation and the non-unified description of the interactions, with gravity completely missing.

For these reasons, the SM is regarded as a low-energy theory bound to fail at some energy scale larger than the Fermi scale, where New Physics (NP) effects become important. The search for these effects beyond the SM is the main goal of particle physics in the next decades, both at present and future experimental facilities.

The most straightforward way to search for NP is producing and observing new particles in colliders. To this end, the key ingredient is the available center-of-mass energy: the higher the energy, the heavier the particles one can produce, thus probing higher NP scales. Pushing forward the energy frontier then means building colliders with higher and higher center-of-mass energy. The problem with direct searches is that their success depends on the unknown production thresholds of the new particles. Some of the SM problems, however, have solutions, such as the natural stabilization of the Fermi scale or the WIMPs (Weakly Interacting Massive Particles) as dark matter candidates, which point to NP at the TeV scale giving to the LHC good chances to discover it.

A complementary way to reveal NP is measuring the effect of virtual heavy particle exchange in processes involving only SM particles as external states. For this kind of searches, called indirect, the production threshold is not an issue. Since quantum effects become typically smaller as the mass of the virtual particles increases, higher NP scales are probed by increasing the precision of the measurements, controlling at same time the SM contributions with an accuracy sufficient to disentangle genuine NP effects from SM uncertainties. Progress at the intensity frontier entails building experimental facilities which can deliver high-intensity beams at energies where one can make a set of precision measurements not limited by systematic and theoretical uncertainties.

Flavor physics is the best candidate as a tool for indirect NP searches for several reasons. Flavor Changing Neutral Currents (FCNC), neutral meson-antimeson mixing and CP violation occur at the loop level in the SM and therefore are potentially subject to large virtual corrections from new heavy particles. In addition, flavor violation in the SM is governed by weak interactions and, in the case of quarks, suppressed by small mixing angles. These features are not necessarily shared by NP which could then produce very large effects.

On quite general grounds, the indirect NP search in flavor processes explores a parameter space including the NP scale and the NP flavor- and CP-violating couplings. In specific models, these are related to fundamental parameters such as masses and couplings of new particles. In particular, an observable NP effect could be generated by small NP scales and/or large couplings. Indeed the inclusion in the SM of generic NP flavor-violating terms with $\mathcal{O}(1)$ couplings is known to violate present experimental constraints unless the NP scale is pushed to large values, from 10^2 to 10^4 TeV depending on the flavor sector, with the larger scales required by kaon physics [1]

The difference between the NP scale emerging from flavor physics when flavor couplings are not suppressed and the TeV scale suggested by the solution of the SM problems mentioned above is usually referred to as the NP flavor problem: NP models with new particles at the TeV scale need a mechanism to suppress NP contributions to FCNC and CP-violating processes. On the other hand, this clearly indicates that flavor physics has either the potential to push the explored NP scales well beyond the TeV region or, if the NP scale is indeed close to 1 TeV, that the NP flavor structure is non-trivial, calling for the experimental determination of new flavor-violating couplings in order to elucidate the suppression mechanism at work.

In spite of its potential, so far flavor physics has not provided a clear NP signal, although deviations with low significance are present here and there. This failure, however, should not be considered discouraging. Broadly speaking, flavor physics probed and excluded only the region of small masses/large NP flavor couplings. On the other hand, we should not forget that flavor physics already proved itself effective in predicting the existence and in some cases the mass of most of the heavy particles which are nowadays part of the SM. The list of these successes includes the prediction of the existence of the charm quark from the suppression of the rate $K^0 \rightarrow \mu^+ \mu^-$ in the early seventies [2], the prediction of the existence of the third generation from the measurement of CP violation in $K-\bar{K}$ mixing, again in the seventies [3] and the indication of a heavy mass for the top quark from the measurements of the semileptonic B decay rates and the $B-\bar{B}$ mass difference in the late eighties [4]. The lesson to be learned from this short historical excursus is that flavor physics can indeed provide very valuable

information on unknown heavy particles and it is therefore worth pushing experiments and theory to higher precision in order to probe heavier particles and/or smaller flavor couplings.

In this paper, we give an overview of the physics opportunities opened by the next-generation flavor experiments, mainly the two approved super B -factories SuperB in Italy and Belle-II/SuperKEKB in Japan. These are actually super flavor-factories, expected to produce precision measurements in B , D and τ physics, increasing by two orders of magnitude the luminosity of their predecessors PEP-II and KEKB. The two super-flavor factories are planned to start to take data in the second part of this decade and to collect more than 50 ab^{-1} integrated luminosity by around 2020. It has to be noted that by ~ 2015 the LHCb experiment at LHC will collect the design integrated luminosity of 10 fb^{-1} and an upgrade (after 2020) is actually under study to considerably increase the collected data sample up to 50 fb^{-1} .

We begin with a brief primer on flavor and CP violation in the SM, introducing also the some common flavor observables, in section 2. We then summarize in section 3 the present knowledge of the SM flavor sector and point out some tensions which could be the harbingers of physics beyond the SM. The most interesting measurements in the physics programme of the next-generation flavor factories are reviewed in section 4, giving estimates of the expected statistical and systematic errors. The selection of these measurements is done taking into account the physics program which should have been already accomplished by LHCb. In section 5, we discuss the impact of these measurements on a selection of NP models in different scenarios, giving few examples of the potential implications of precision flavor physics. Finally, our conclusions are presented in section 6.

We are particularly indebted with the authors of refs. [5, 6, 7, 8, 9], as many arguments and results presented in this review are based on their studies.

2 Flavor and CP violation: a short primer

In this section we briefly review the SM flavor structure, focusing mainly on the quark sector and collecting some basic formulae used throughout the review.

2.1 Flavor and CP violation in the Standard Model

The SM matter content is organized as follows:

$$\begin{aligned} \text{quarks : } & Q_L^i \left(3, 2, \frac{1}{6} \right), \quad U_R^i \left(3, 1, \frac{2}{3} \right), \quad D_R^i \left(3, 1, -\frac{1}{3} \right) \\ \text{leptons : } & L_L^i \left(1, 2, -\frac{1}{2} \right), \quad E_R^i (1, 1, -1), \end{aligned} \quad (1)$$

where the transformation properties under the gauge groups $SU(3)_C \times SU(2)_L \times U(1)_Y$ are indicated. The index i spans the flavor space. In the SM with three generations, one has

$$\begin{aligned} Q_L^i &= \begin{pmatrix} u_L^i \\ d_L^i \end{pmatrix}, \quad L_L^i = \begin{pmatrix} \nu_L^i \\ \ell_L^i \end{pmatrix}, \quad U_R^i = u_R^i, \quad D_R^i = d_R^i, \quad E_R^i = \ell_R^i, \\ u^i &= (u, c, t), \quad d^i = (d, s, b), \quad \ell = (e, \mu^-, \tau^-), \quad \nu^i = (\nu^e, \nu^\mu, \nu^\tau). \end{aligned} \quad (2)$$

The subscripts L and R denote the left-handed and right-handed components of the fields. The SM Lagrangian can be written as

$$\mathcal{L}^{\text{SM}} = \mathcal{L}^{\text{Yang-Mills}} + \mathcal{L}^{\text{Dirac+gauge}} + \mathcal{L}^{\text{Higgs}} + \mathcal{L}^{\text{Yukawa}}. \quad (3)$$

In the absence of $\mathcal{L}^{\text{Yukawa}}$, the SM Lagrangian is invariant under the global symmetry

$$G_{\text{flavor}} = U(3)_Q \otimes U(3)_U \otimes U(3)_D \otimes U(3)_L \otimes U(3)_E, \quad (4)$$

corresponding to the separate unitary rotation of each matter multiplet in flavor space. $\mathcal{L}^{\text{Yukawa}}$ contains the Yukawa interactions between the Higgs doublet and the matter fields:

$$\mathcal{L}^{\text{Yukawa}} = \bar{Q}_L^i Y_u^{ij} U_R^j \tilde{H} + \bar{Q}_L^i Y_d^{ij} D_R^j H + \bar{L}_L^i Y_\ell^{ij} E_R^j H + \text{H.c.}, \quad (5)$$

where H is the Higgs doublet transforming as $(1, 2, 1/2)$ and $\tilde{H} = i\sigma_2 H^* (1, 2, -1/2)$. The Yukawa couplings $Y_{u,d,\ell}$ are 3×3 complex matrices in flavor space (the sum over the flavor indices i, j is understood). The presence of non-vanishing Yukawa couplings breaks this large group down to few $U(1)$ factors,

$$G_{\text{flavor}} \xrightarrow{Y_{u,d,\ell} \neq 0} U(1)_B \otimes U(1)_e \otimes U(1)_\mu \otimes U(1)_\tau, \quad (6)$$

which account for the conservation of the baryon and the three lepton numbers.

They can be diagonalized using the singular value decomposition, giving

$$Y_u^{\text{diag}} = U_L^u Y_u U_R^{u\dagger}, \quad Y_u^{\text{diag}} = U_L^d Y_u U_R^{d\dagger}, \quad (7)$$

where $U_{L,R}^{u,d}$ are four unitary matrices and $Y_{u,d}^{\text{diag}}$ are diagonal matrices with real non-negative matrix elements. Therefore it is always possible to choose a flavor basis for the quark fields where, for example,

$$Y_d = Y_d^{\text{diag}}, \quad Y_u = V^\dagger Y_u^{\text{diag}}. \quad (8)$$

$V = U_L^u U_L^{d\dagger}$ is the Cabibbo-Kobayashi-Maskawa matrix [11, 3] which contains all flavor non-diagonal couplings and the only CP-violating phase of the SM Lagrangian (notice however that the flavor symmetry is broken also by $Y_{u,d}^{\text{diag}}$ as long as the diagonal entries are different). Clearly V originates from the misalignment in flavor space of the components of the left-handed quark doublet.

After the Electroweak Symmetry Breaking (EWSB), the Yukawa interactions generate the fermion masses. Replacing $H \rightarrow (0, v/\sqrt{2})$ in eq. (5), one obtains

$$\mathcal{L}^{\text{mass}} = \bar{u}_L^i M_{ij}^u u_R^j + \bar{d}_L^i M_{ij}^d d_R^j + \text{H.c.}, \quad M^u = Y_u \frac{v}{\sqrt{2}}, \quad M^d = Y_d \frac{v}{\sqrt{2}}. \quad (9)$$

One can go to the mass eigenstate basis, where M^u and M^d are both diagonal, applying unitary flavor transformations to the quark fields, namely making the replacement

$$u_{L,R} \rightarrow U_{L,R}^{u\dagger} u_{L,R}, \quad d_{L,R} \rightarrow U_{L,R}^{d\dagger} d_{L,R}, \quad (10)$$

where $U_{L,R}^{u,d}$ are the four unitary matrices defined in eq. (7). The only leftover of these transformations in the SM Lagrangian is the CKM matrix appearing in the charged current weak interactions

$$\mathcal{L}^{\text{cc}} = \frac{g_2}{\sqrt{2}} \bar{u}_L^i \gamma_\mu V_{ij} d_L^j W^\mu + \text{H.c.} \quad (11)$$

where g_2 is the $SU(2)$ coupling constant.

Let us have a closer look at the CKM matrix V . A generic 3×3 unitary matrix can be represented using 3 Euler angles and 6 phases, but 5 of the latter can be removed by re-phasing the quark fields. Therefore V can be parameterized by 3 angles $\theta_{12}, \theta_{23}, \theta_{13} \in [0, \pi/2]$ and 1 phase $\delta \in [-\pi, \pi]$. Notice that the choice of the parameters is not unique. In the parameterization used by the PDG [12], the CKM matrix reads

$$V \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23}-c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23}-s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23}-c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23}-s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}, \quad (12)$$

where $s_{ij} = \sin \theta_{ij}$ and $c_{ij} = \cos \theta_{ij}$.

The CP-violating phase δ is not a physical parameter as it depends on the phase conventions of the quark fields. An invariant condition for CP violation in the SM is given by [13]

$$0 \neq \det \left[M^u M^{u\dagger}, M^d M^{d\dagger} \right] = 2iJ (m_u^2 - m_c^2)(m_c^2 - m_t^2)(m_t^2 - m_u^2)(m_d^2 - m_s^2)(m_s^2 - m_b^2)(m_b^2 - m_d^2), \quad (13)$$

where the Jarlskog invariant $J = |\text{Im}(V_{ij}V_{kl}V_{il}^*V_{kj}^*)|$ (for all $i \neq k$ and $j \neq l$) is independent of the convention chosen for the CKM matrix. In terms of the parameters used in eq. (12), $J =$

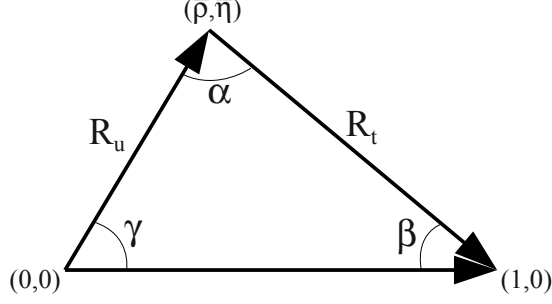


Figure 1: The Unitarity Triangle

$s_{12}s_{13}s_{23}c_{12}c_{13}^2c_{23}\sin\delta$. Therefore CP violation in the SM requires $\delta \neq 0, \pi$, non-degenerate masses in the up and down sectors and non-trivial mixing angles $\theta_{ij} \neq 0, \pi/2$.

The unitarity of V implies 9 conditions involving products of rows (or columns) of the form $\sum_k V_{ik}V_{jk}^* = \delta_{ij}$. The off-diagonal relations are called triangular as they define triangles in the complex plane. Remarkably, the area of all these triangles is a constant equal to $J/2$ and thus a measure of CP violation in the SM. One of them, of particular phenomenological interest, is referred to as the Unitarity Triangle (UT):

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0. \quad (14)$$

The UT can be rewritten in the normalized form

$$R_t e^{-i\beta} + R_u e^{i\gamma} = 1, \quad (15)$$

with

$$R_t = \left| \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \right|, R_u = \left| \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right|, \beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right), \quad (16)$$

being two sides and two angles as sketched in fig. 1. The third side is the unity vector, while the third angle is $\alpha = \pi - \beta - \gamma = \arg(-V_{td}V_{tb}^*/(V_{ud}V_{ub}^*))$. Similarly, it is useful to define the angle $\beta_s = \arg(-V_{ts}V_{tb}^*/(V_{cs}V_{cb}^*))$ from the triangle $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$, as the phase of the B_s - \bar{B}_s mixing amplitude is $-2\beta_s$ in the phase convention of eq. (12). The UT sides and angles are observables and we discuss their present determination from K - and B -meson physics in section 3.

Given the definition in eq. (15), all the information related to the UT is encoded in one complex number

$$\bar{\rho} + i\bar{\eta} = R_u e^{i\gamma} \quad (17)$$

corresponding to the coordinates $(\bar{\rho}, \bar{\eta})$ in the complex plane of the only non-trivial apex of the UT.

It is worth mentioning another popular CKM parameterization introduced by Wolfenstein [14] which allows to write an expansion of the CKM matrix in terms of a small parameter λ :

$$V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4) \quad (18)$$

This parameterization makes explicit the hierarchy of CKM matrix elements, showing that quark flavor-changing transitions are suppressed in the SM. The exact relations between the PDG and the Wolfenstein parameterizations are

$$\lambda = \sin\theta_{12}, \quad A = \frac{\sin\theta_{23}}{\sin^2\theta_{12}}, \quad \rho = \frac{\sin\theta_{13}\cos\delta}{\sin\theta_{12}\sin\theta_{23}}, \quad \eta = \frac{\sin\theta_{13}\sin\delta}{\sin\theta_{12}\sin\theta_{23}}. \quad (19)$$

Notice that $\lambda \sim 0.22$ (the sine of the Cabibbo angle θ_{12}) is indeed a good expansion parameter. The relation between the UT apex coordinates and the Wolfenstein parameters is

$$\rho + i\eta = \sqrt{\frac{1 - A^2\lambda^4}{1 - \lambda^2}} \frac{\bar{\rho} + i\bar{\eta}}{1 - A^2\lambda^4(\bar{\rho} + i\bar{\eta})} \simeq \left(1 + \frac{\lambda^2}{2}\right) (\bar{\rho} + i\bar{\eta}) + \mathcal{O}(\lambda^4). \quad (20)$$

showing that $\bar{\rho} = \rho$ and $\bar{\eta} = \eta$ at the lowest order in λ .

For massless neutrinos, the SM lepton sector is flavor diagonal and CP conserving, as Y_ℓ can be chosen real and diagonal. Once the SM is trivially extended to include right-handed neutrinos and account for neutrino Dirac masses, introducing an additional Yukawa matrix Y_ν , the formalism for lepton flavor and CP violation is similar to the quark one. The lepton mixing matrix, called the Pontecorvo-Maki-Nakagawa-Sakata matrix, [15], is parameterized much as the CKM matrix. The only difference is that the possibility of having Majorana mass terms for neutrinos allows for two additional CP-violating phases. In spite of these formal similarities, the flavor phenomenology of the lepton sector, in particular of neutrinos, is rather different from the quark one and its discussion goes beyond the scope of this primer. We just remind that, given the smallness of neutrino masses, charged lepton flavor violation is negligible in the SM.

2.2 Meson mixing and CP violation

Most of flavor physics deals with flavor-changing transitions involving mesons. As far as decays are concerned, CP violation appears as a difference between the rates of a decay and its CP-conjugate, accounted for by the direct CP asymmetry

$$A_{\text{CP}} = \frac{\Gamma(\bar{M} \rightarrow \bar{f}) - \Gamma(M \rightarrow f)}{\Gamma(\bar{M} \rightarrow \bar{f}) + \Gamma(M \rightarrow f)} = \frac{|\bar{A}|^2 - |A|^2}{|\bar{A}|^2 + |A|^2}, \quad (21)$$

where M is the decaying meson, f is the final state, \bar{M} and \bar{f} are the CP-conjugate states and A and \bar{A} are the two decay amplitudes. Charged mesons can only violate CP in the decay. On the other hand, neutral mesons, with the exception of the pion, are subject to the mixing phenomenon, *i.e.* the mass eigenstates are a superposition of the flavor ones. In this case, CP violation can also occur in the mixing itself and in the interference between mixing and decay, giving additional opportunities to observe it. We briefly summarize in the following the main formulae related to meson mixing and CP violation.

The time evolution of a system of unstable neutral meson-antimeson states $M-\bar{M}$ can be described by a 2×2 non-Hermitian matrix Hamiltonian \hat{H}

$$i \frac{d}{dt} \begin{pmatrix} |M(t)\rangle \\ |\bar{M}(t)\rangle \end{pmatrix} = \hat{H} \begin{pmatrix} |M(t)\rangle \\ |\bar{M}(t)\rangle \end{pmatrix} = \left(\hat{m} - \frac{i}{2} \hat{\Gamma} \right) \begin{pmatrix} |M(t)\rangle \\ |\bar{M}(t)\rangle \end{pmatrix}. \quad (22)$$

\hat{H} can be decomposed using the two Hermitian matrices \hat{m} and $\hat{\Gamma}$ representing its dispersive and absorptive part respectively. In particular, assuming CPT invariance, one can write

$$\hat{m} = \begin{pmatrix} m & m_{12} \\ m_{12}^* & m \end{pmatrix}, \quad \hat{\Gamma} = \begin{pmatrix} \Gamma & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma \end{pmatrix}. \quad (23)$$

The eigenstates of \hat{H} , denoted as $|M_{L,H}\rangle$, can be written as

$$|M_{L,H}\rangle = \frac{1}{\sqrt{1+|q/p|^2}} (|M\rangle \pm q/p |\bar{M}\rangle), \quad q/p = -\sqrt{\frac{m_{12}^* - \frac{i}{2}\Gamma_{12}^*}{m_{12} - \frac{i}{2}\Gamma_{12}}}, \quad (24)$$

where L (H) corresponds to the upper (lower) sign. The corresponding eigenvalues are

$$m_{L,H} - \frac{i}{2}\Gamma_{L,H} = m - \frac{i}{2}\Gamma \mp \sqrt{\left(m_{12} - \frac{i}{2}\Gamma_{12}\right) \left(m_{12}^* - \frac{i}{2}\Gamma_{12}^*\right)}, \quad (25)$$

giving the mass and width differences between the two eigenstates

$$\begin{aligned} \Delta m &= m_H - m_L = 2 \operatorname{Re} \sqrt{\left(m_{12} - \frac{i}{2}\Gamma\right) \left(m_{12}^* - \frac{i}{2}\Gamma^*\right)}, \\ \Delta \Gamma &= \Gamma_H - \Gamma_L = -4 \operatorname{Im} \sqrt{\left(m_{12} - \frac{i}{2}\Gamma\right) \left(m_{12}^* - \frac{i}{2}\Gamma^*\right)}. \end{aligned} \quad (26)$$

These observables, or the corresponding dimensionless variables $x = \Delta m/\Gamma$ and $y = \Delta\Gamma/2\Gamma$ (Γ is the average lifetime), characterize the mixing. In addition, the absolute value $|q/p|$ is also observable. The deviation of $|q/p|$ from one is a measure of CP violation in the mixing, as shown by the expression of the semileptonic CP asymmetry¹

$$\begin{aligned} A_{\text{SL}} &= \frac{\Gamma(\bar{M} \rightarrow X\ell^+\nu_\ell) - \Gamma(M \rightarrow X\ell^-\bar{\nu}_\ell)}{\Gamma(\bar{M} \rightarrow X\ell^+\nu_\ell) + \Gamma(M \rightarrow X\ell^-\bar{\nu}_\ell)} \\ &= \frac{1 - |q/p|^4}{1 + |q/p|^4} = \frac{\text{Im}(m_{12}^*\Gamma_{12})}{|m_{12}|^2 + \frac{1}{4}|\Gamma_{12}|^2}. \end{aligned} \quad (27)$$

Depending on the meson, these formulae can be approximated in different ways. For B mesons, where $\Gamma_{12} \ll m_{12}$, one finds

$$\begin{aligned} \Delta m &\simeq 2|m_{12}|, \quad \Delta\Gamma \simeq \Delta m \text{Re}\left(\frac{\Gamma_{12}}{m_{12}}\right), \\ |q/p| &\simeq 1 - \frac{1}{2}\text{Im}\frac{\Gamma_{12}}{m_{12}}, \quad A_{\text{SL}} \simeq \text{Im}\left(\frac{\Gamma_{12}}{m_{12}}\right). \end{aligned} \quad (28)$$

For the D meson such simplification is not possible and the full expressions have to be used. Besides, eqs. (26) only give the short-distance part of the corresponding observables, which contain large long-distance contributions. For kaons, the eigenstates are usually parameterized in terms of $\bar{\varepsilon} = (1 + q/p)/(1 - q/p)$ and different approximations hold, see for example ref. [10] for details on kaon mixing.

Finally, the third manifestation of CP violation in meson decays is through the interference between mixing and decay. The key observable in this case is the time-dependent CP asymmetry of a meson state $M(t)$ decaying into a final state f . Taking a CP-eigenstate final state and up to $\mathcal{O}(|q/p|^2 - 1)$ corrections, the asymmetry is given by

$$\begin{aligned} A_{\text{CP}}^{M \rightarrow f}(t) &= \frac{\Gamma(M(t) \rightarrow f) - \Gamma(\bar{M}(t) \rightarrow f)}{\Gamma(M(t) \rightarrow f) + \Gamma(\bar{M}(t) \rightarrow f)} \\ &\simeq \frac{C_{M \rightarrow f} \cos(\Delta m t) - S_{M \rightarrow f} \sin(\Delta m t)}{\cosh(\frac{\Delta\Gamma}{2}t) + S'_{M \rightarrow f} \sinh(\frac{\Delta\Gamma}{2}t)}, \end{aligned} \quad (29)$$

where

$$C_{M \rightarrow f} = \frac{1 - |\lambda_{M \rightarrow f}|^2}{1 + |\lambda_{M \rightarrow f}|^2}, \quad S_{M \rightarrow f} = \frac{2 \text{Im}(\lambda_{M \rightarrow f})}{1 + |\lambda_{M \rightarrow f}|^2}, \quad S'_{M \rightarrow f} = \frac{2 \text{Re}(\lambda_{M \rightarrow f})}{1 + |\lambda_{M \rightarrow f}|^2}, \quad (30)$$

with

$$\lambda_{M \rightarrow f} = (q/p)_M \frac{\bar{A}}{A}. \quad (31)$$

$(q/p)_M$ is the M mixing parameter and A (\bar{A}) is the amplitude for $M \rightarrow f$ ($\bar{M} \rightarrow f$). The coefficient $C_{M \rightarrow f} \simeq -A_{\text{CP}}$, the direct CP asymmetry defined in eq. (21). The coefficient $S_{M \rightarrow f}$, instead, is a new measurement of CP violation generated by the interference of mixing and decay amplitudes.

Time-dependent CP asymmetries for B decays (where $\Delta\Gamma \sim 0$) give access to the UT angles. For example, as the amplitude for $B_d \rightarrow J/\psi K_S$ is dominated by a single term with a definite weak phase, one finds

$$A_{\text{CP}}^{B_d \rightarrow J/\psi K_S}(t) = -S_{B_d \rightarrow J/\psi K_S} \sin(\Delta m t), \quad S_{B_d \rightarrow J/\psi K_S} \simeq \sin 2\beta, \quad (32)$$

up to doubly Cabibbo-suppressed corrections. In other cases, the decay amplitude is not dominated by a single term and the extraction of the UT angles is less straightforward, as hadronic amplitudes no longer cancel in $\lambda_{M \rightarrow f}$. Previous formulae can also be generalized to non CP-eigenstate final states [16].

¹This formula is correct for $M = K^0, B_d, B_s$. For D^0 mesons, the leptons in the final state are CP conjugated.

3 Present Status of Flavor Physics

In this section, we briefly review the present status of flavor physics in the SM, discussing the determination of the CKM parameters and possible deviations found in present data.

3.1 Determination Of The Cabibbo-Kobayashi-Maskawa Matrix

The CKM matrix elements $|V_{ud}|$ and $|V_{us}|$ can be measured from super-allowed β decays [17] and semileptonic/leptonic kaon decays [18] respectively, determining accurately the sine of the Cabibbo angle. The other CKM parameters are determined through a fit to the UT in eq. (15), as shown in fig. 2, using the latest determinations of the theoretical and experimental parameters [19]. The basic constraints are $|V_{ub}/V_{cb}|$ from semileptonic B decays, Δm_d and Δm_s from $B_{d,s}$ oscillations, ε_K from $K^0-\bar{K}^0$ mixing, α from charmless hadronic B decays, γ and $2\beta+\gamma$ from charm hadronic B decays, $\sin 2\beta$ from $B^0 \rightarrow J/\psi K^0$ decays and the $\text{BR}(B \rightarrow \tau\nu)$ [20].

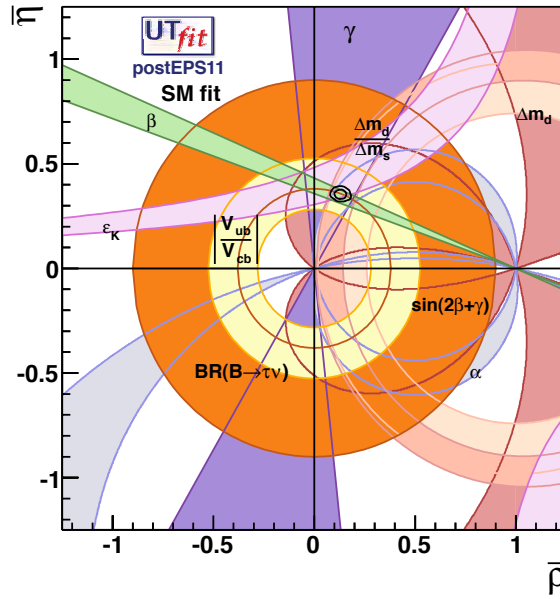


Figure 2: Determination of $\bar{\rho}$ and $\bar{\eta}$ selected from constraints on $|V_{ub}/V_{cb}|$, Δm_d , Δm_s , ε_K , α , β , γ , $2\beta+\gamma$ and $\text{BR}(B \rightarrow \tau\nu)$. 68% and 95% total probability contours are shown, together with 95% probability regions from the individual constraints.

The consistency between the different constraints clearly establishes the CKM matrix as the dominant source of flavor mixing and CP-violation, described by a single parameter $\bar{\eta}$.

3.2 Possible Hints of New Physics

The consistency of the CKM picture can be quantitatively tested comparing the direct measurement of a flavor observable entering the UT fit with the SM prediction obtained from the UT fit without using the constraint being tested.

Table 1 contains a set of flavor observables: for each of them, the SM prediction, the measurement, and the pull (the difference of prediction and measurement in unit of σ) are shown. At present, the main tensions in the UT fit come from $\text{BR}(B \rightarrow \tau\nu)$, which is found to deviate from the measurement by $\sim 3.2\sigma$, and $\sin 2\beta$, which is larger than the experimental value by $\sim 2.6\sigma$. It is interesting to note that the former prefers large values of $|V_{ub}/V_{cb}|$, while the latter wants $|V_{ub}/V_{cb}|$ to be small. Any change of the measured value of $|V_{ub}|$ and $|V_{cb}|$ will not improve the situation.

In the B_s sector, the possibility of a large deviation in β_s is still open, although new Tevatron data on $B_s \rightarrow J/\psi\phi$, still to be included in the average [21], go in the SM direction [22, 23]. Moreover, the dimuon asymmetry $A_{\mu\mu}$ measured by DØ [24] also displays a large deviation from the SM, pointing to a large β_s and possibly to NP contributions in $\Delta\Gamma_s$.

Table 1: Summary of different measurements and corresponding SM predictions. In the last column the pull is explicitly indicated.

Observable	Prediction	Measurement	Pull (σ)
γ [$^\circ$]	69.6 ± 3.1	74 ± 11	-0.4
α [$^\circ$]	85.4 ± 3.7	91.4 ± 6.1	-0.8
$\sin 2\beta$	0.771 ± 0.036	0.654 ± 0.026	+2.6
$ V_{ub} $ [10^{-3}]	3.55 ± 0.14	3.76 ± 0.20	-0.9
$ V_{cb} $ [10^{-3}]	42.69 ± 0.99	40.83 ± 0.45	+1.6
ε_K [10^{-3}]	1.92 ± 0.18	2.23 ± 0.010	-1.7
$BR(B \rightarrow \tau\nu)$ [10^{-4}]	0.805 ± 0.071	1.72 ± 0.28	-3.2
Δm_s [ps^{-1}]	17.77 ± 0.12	18.3 ± 1.3	-0.4
β_s [$^\circ$]	1.08 ± 0.04	Tevatron	+2.1
$\Delta\Gamma_s$ [ps^{-1}]	0.11 ± 0.02	average	+2.1
$A_{\mu\mu}$ [10^{-4}]	-1.7 ± 0.5	-95.7 ± 29.0	+3.2

4 Opportunities From Precision Flavor Physics

4.1 B Physics

4.2 CP Violation

In this section we describe the golden modes related to CP violation measurements. Among the CP-violating observable there are the UT triangle angles β , α , γ and β_s , the mixing-induced CP violation in charmless hadronic B decays, in $b \rightarrow s\gamma$ transitions and the direct CP violation in $b \rightarrow s\gamma$ and $b \rightarrow s\ell\ell$ decays.

4.2.1 CP violation in $b \rightarrow c\bar{c}s$ transition: angles β and β_s

The mixing induced CP asymmetry in $B \rightarrow J/\psi K_S^0$ transition allows to measure the angle β of the UT in a theoretically clean way. The measurement of this CP asymmetry was the golden mode for the past generation of B -factories which finally measured $\sin 2\beta = 0.654 \pm 0.026$ [19]. In Section 3 we have shown that this parameter deviates 2.6σ from the SM. Thus improving the precision of this measurement is particularly important. Its present error is still dominated by a statistical component of about 0.010. If this measurement is performed in a B -factory-like environment, the statistical precision will match the systematic one for an integrated luminosity of about 10 ab^{-1} . Some preliminary study has shown that a better understanding of the detector and the use of control sample on data could allow to reduce the systematics to get a final experimental error of about 0.005. At this level of precision the theoretical error matters yet it is possible to control it via a data-driven approach by measuring the time-dependent CP asymmetry in $B^0 \rightarrow J/\psi\pi^0$ [25]. One can conclude that it is possible to discover NP (at 5σ) if there is a deviation of 0.02 from the SM expectation for $\sin 2\beta$ as measured in tree decays [9]. Notice that the precision of this measurement is not expected to improve much at hadronic machines.

Similarly, the mixing induced CP asymmetry in $B_s \rightarrow J/\psi\phi$ allows to measure the angle β_s . The SM value for this angle is very small, about 0.02. This analysis has already been performed at the Tevatron and will be one of the golden channels of the LHCb physics program. CDF and DØ have performed this analysis finding β_s in $[0.02, 0.52] \cup [1.08, 1.55]$ at 68% C.L. [22] and $-2\beta_s = -0.76_{-0.36}^{+0.38} \pm 0.02$ [23] respectively. The Tevatron average, available only for older data, gives β_s in $[0.27, 0.59] \cup [0.97, 1.30]$ at 68% C.L. [21]

LHCb should reach a sub-degree (0.5°) precision with about 10 fb^{-1} . At this level of precision the theoretical error matters, but it can be controlled with data-driven methods [26]. Careful studies of systematic errors have to be performed to prove that the precision can be further improved with a larger data sample (LHCb upgrade).

4.2.2 CP violation in $b \rightarrow s\bar{s}q$ transition

The measurement of the mixing-induced CP violation in the $b \rightarrow s\bar{s}q$ is interesting, since new particles in the loop can cause deviations from SM predictions. In the SM these decays measure $\sin 2\beta$ up to channel-dependent corrections. Many channels have been measured at the B -factories and the “golden four” theoretically cleanest ones are [9]: $B \rightarrow (\phi K^0) B \rightarrow \eta' K^0$, $B^0 \rightarrow f_0 K^0$, $B \rightarrow K^0 K^0 K^0$. For these channels, $\Delta S = S(css) - S(J/\psi K_S^0)$ has been evaluated using hadronic models based on factorization [27] and found to be small (~ 0.02) with an uncertainty of about 0.02. However we stress that not all sources of theoretical error are under control in these estimates. On the other hand, data-driven methods can benefit from precision measurements so that other modes, such as $B \rightarrow K_S \pi^0$ [28], could become competitive at next-generation experiments.

From the experimental point of view, it has been shown that the precision of S measured for the “golden four” can be pushed down to about 0.02 (0.01 in case of $\eta' K^0$) with about 75 ab^{-1} . In case a sizable ΔS , between 0.05 and 0.10, is found in these measurements, further theoretical and phenomenological work will be required to pin down the SM value and firmly establish the presence of NP. In this respect, the opportunity of measuring several modes with different theoretical uncertainties, but possibly correlated NP contributions, is a unique advantage of super flavor factories.

In this panorama, LHCb can contribute with one measurement, $S(B_s \rightarrow \phi\phi)$, reaching a precision of about 0.03.

4.2.3 CP violation in charmless $B \rightarrow \pi(\rho)\pi(\rho)$ decays: angle α

The angle α can be obtained using the time-dependent analyses of $B^0 \rightarrow \pi^+\pi^-$, $B^0 \rightarrow \rho^+\rho^-$ and $B^0 \rightarrow (\rho\pi)^0$. These charmless decays are dominated by the $b \rightarrow u$ tree amplitude (T). Neglecting the second amplitude with a different weak phase, the so-called penguin amplitude (P), these decays give a measurement of $\sin 2\alpha$. Actually the experimentally measured quantity is $\sin 2\alpha_{eff}$, which is a function of $\sin 2\alpha$ but also of the unknown hadronic parameter P/T . Several strategies have been proposed to get rid of this “penguin pollution”. The original method uses an analysis of all the $B \rightarrow \pi\pi$ decays based on the $SU(2)$ flavor symmetry [29]. The B -factories have measured $\alpha = (91.4 \pm 6.1)^\circ$. With the full dataset, super flavor factories will measure α with precision of $(2 - 3)^\circ$ separately for $B^0 \rightarrow \pi^+\pi^-$, $B^0 \rightarrow \rho^+\rho^-$ and $B^0 \rightarrow (\rho\pi)^0$ decay modes. At this level of accuracy, isospin violation may become relevant. However, super flavor factories permit a multi-approach strategy allowing to test the consistency among results for α obtained in different channels.

The measurement of α will be extremely difficult in a hadronic environment (but for one measurement at about 5° in the $\rho\pi$ channel) since it typically requires the reconstruction of decay modes containing several neutral particles.

4.2.4 CP violation in $B \rightarrow DK$ transition: angle γ

Various methods related to $B \rightarrow DK$ decays have been proposed to determine the UT angle γ [30, 31, 32, 33], using the fact that a charged B can decay into a $D^0(\bar{D}^0)K$ final state via a $V_{cb}(V_{ub})$ mediated process. CP violation occurs if D^0 and \bar{D}^0 decay to the same final state. These processes are thus sensitive to the phase difference γ between V_{ub} and V_{cb} . The same argument can be applied to $B \rightarrow D^*K$ and $B \rightarrow D^{(*)}K^*$ decays and for neutral B decays such as $B^0 \rightarrow D^0(\bar{D}^0)K^{*0}$.

The angle γ has been measured at B -factories with an unexpected precision : $\gamma = (74 \pm 11)^\circ$ with a 180° ambiguity. Using all the different methods and the large data set available from next-generation experiments, the precision on γ can be improved down to the degree level, where the precision will be

still dominated by the statistical error. It has to be noted that LHCb is expected to reach a precision on γ of about $(2-3)^\circ$ with about 10 fb^{-1} .

4.2.5 CP violation in radiative $b \rightarrow s\gamma$ decays

The study of the direct CP asymmetry in radiative B decays is one of the golden modes of the physics programme at super flavor factories. This asymmetry is predicted very small, of order 0.5%, in SM and with a relatively small theoretical uncertainty. The exclusive decays $A_{CP}(B \rightarrow K^*\gamma)$ have been actually measured at the present B -factories and is compatible with zero within an error of about 0.025. The present error is already limited by systematic effects due to asymmetries in the detector response to positive and negative kaons. Recent studies has shown the use of large data control sample could allow to push the precision down to 0.5%. The inclusive decays have been also studied at the present B -factories and A_{CP} found compatible with zero. Also in this case the error with the 75 ab^{-1} could be pushed down to 0.5%.

In the SM, the asymmetry $A_{CP}(B \rightarrow X_{d+s}\gamma)$ is expected to vanish. From the experimental point of view, the study of this sample is interesting since the systematics from the particle identification does not contribute. On the other hand one has to deal with a larger background. Preliminary studies have shown that a sub-percent precision is reachable with 75 ab^{-1} at the super flavor factories.

4.2.6 CP violation in radiative $b \rightarrow s\ell^+\ell^-$ decays

The exclusive mode $B \rightarrow K^*\mu^+\mu^-$ will be deeply studied by LHCb and several observable precisely measured. Nevertheless, these exclusive measurements will be limited by hadronic uncertainties. The role of next-generation experiments in this sector is to provide theoretically cleaner measurements of the same observables using inclusive modes. Recent studies has shown that a sample exceeding 10 ab^{-1} is needed to take advantage of the theoretical cleanliness of several inclusive observables, such as the zero-crossing of the forward-backward asymmetry in $b \rightarrow s\ell^+\ell^-$ [9].

4.2.7 CP violation in radiative $b \rightarrow s\gamma$ decays and photon polarization

Within the SM, the photon emitted in radiative b (\bar{b}) decays are predominately left (right)-handed. The measurement of the mixing-induced CP asymmetry allows to probe the interference between b and \bar{b} decays and thus the polarization of the photon. In the SM the value of the parameter S is expected to be below 5%. The current B -factories have measured $S(B \rightarrow K_S\pi^0\gamma)$ with about 25% precision. This measurement can be converted to an uncertainty of about 0.16 on the fraction of the wrongly-polarized photons ($R(\text{wrong})$). The uncertainty is dominated by the statistical error. The critical point for this measurement is the efficiency in the reconstruction of the K_S^0 which depends crucially on the radius of the silicon detector. Recent sensitivity studies have shown that the error on S can be pushed down to 0.02 and thus to about 0.02–0.03 on $R(\text{wrong})$ with a dataset of 75 ab^{-1} .

Similar analyses can be performed by LHCb using $B \rightarrow \phi\gamma$. Using the full dataset, a precision of about 0.1 on $R(\text{wrong})$ can be achieved. It is worth noting that $B \rightarrow K^*e^+e^-$ can give a competitive measurement of $R(\text{wrong})$.

4.3 Rare Decays

4.3.1 $B \rightarrow K^{(*)}\nu\bar{\nu}$ decay modes

The rare decay $B \rightarrow K^{(*)}\nu\bar{\nu}$ is an interesting probe of NP in Z^0 penguins [34], as for example chargino-up-squark contributions in a generic supersymmetric theory. The $b \rightarrow s\nu\bar{\nu}$ transition is governed by the effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^*(C_L^\nu\mathcal{O}_L^\nu + C_R^\nu\mathcal{O}_R^\nu) + \text{H.c.}, \quad (33)$$

where the operators are $\mathcal{O}_{L,R}^\nu = \frac{e^2}{8\pi^2}(\bar{s}\gamma_\mu P_{L,R}b)(\bar{\nu}\gamma^\mu P_L\nu)$, and the $C_{L,R}^\nu$ are the corresponding Wilson coefficients. In the SM, $C_L^\nu \approx -6.38$ and the C_R^ν vanishes. Observables in $B \rightarrow K^{(*)}\nu\bar{\nu}$ decays only depend on two independent combinations of these Wilson coefficients, which can be written as [35]

$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\text{SM}}|}, \quad \eta = \frac{-\text{Re}(C_L^\nu C_R^{\nu*})}{|C_L^\nu|^2 + |C_R^\nu|^2}, \quad (34)$$

with $(\epsilon, \eta)_{\text{SM}} = (1, 0)$.

Due to presence of two undetected neutrinos the analyses of these decay modes are particularly challenging. Recent studies have shown that the 3σ observation of $\text{BR}(B \rightarrow K\nu\bar{\nu})$ is expected with a data sample of 10 ab^{-1} at super flavor factories, while 50 ab^{-1} will be needed to observe $B \rightarrow K^*\nu\bar{\nu}$, assuming the SM decay rates. In addition the longitudinal polarization fraction F_L for $B \rightarrow K^*\nu\bar{\nu}$ can also be measured with the decent precision of about 20%.

The combination of this information with the measurement of the branching ratios would provide a constraint in the plane (ϵ, η) , as shown in Fig. 3, where NP would show up as a deviation from the SM values $(1, 0)$.

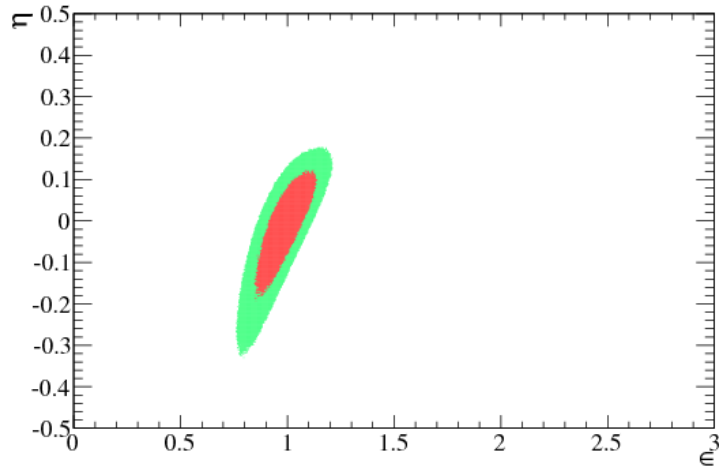


Figure 3: Expected constraint on the (ϵ, η) plane from the measurement of $\text{BR}(B \rightarrow K^{(*)}\nu\bar{\nu})$ and the angular analysis of $B^0 \rightarrow K^{*0}\nu\bar{\nu}$ with a dataset of 75 ab^{-1} .

4.3.2 The leptonic branching fractions $B \rightarrow \ell\nu$

Precision measurements of the branching fraction of $B \rightarrow \ell\nu$ where $\ell = e, \mu, \tau$ can be used to constrain NP contributions which could enhance it, see for example ref. [5]. Fig. 4 shows a comparison of exclusion plots in the $m(H^+)$ - $\tan\beta$ plane of a Two-Higgs-Doublet Model (Type II) coming from a measurement of $\text{BR}(B \rightarrow \tau\nu)$ and $\text{BR}(B \rightarrow \mu\nu)$ with different data samples, 2 ab^{-1} , 10 ab^{-1} , 75 ab^{-1} and 200 ab^{-1} , assuming SM values for the BRs.

Moving from 10 ab^{-1} to 75 ab^{-1} , the channel $B \rightarrow \mu\nu$, which is experimentally cleaner, begins to give a significant contribution to the average, and the gain is then larger than the naive statistical expectation. Increasing the integrated luminosity beyond 75 ab^{-1} , $B \rightarrow \mu\nu$ overtakes $B \rightarrow \tau\nu$ which becomes systematic limited.

It is clear from fig. 4 that the presence of charged Higgs with mass beyond the TeV could be detected in scenario with high $\tan\beta$.

4.3.3 The leptonic $B \rightarrow \ell^+\ell^-$

The decay $B_s \rightarrow \mu^+\mu^-$ suffers from loop and helicity suppressions in the SM and is predicted to be extremely small, $\text{BR}(B_s \rightarrow \mu^+\mu^-) = (3.7 \pm 0.5) \times 10^{-9}$ [36]. NP extensions of the SM do not

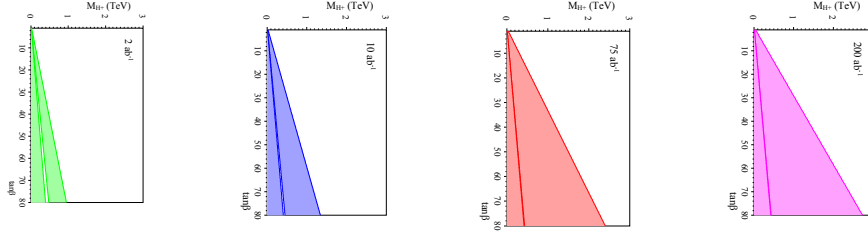


Figure 4: Exclusion regions in the $m(H^+)$ – $\tan\beta$ plane arising from the combinations of the measurement of $\mathcal{B}(B \rightarrow \tau\nu)$ and $\mathcal{B}(B \rightarrow \mu\nu)$ using 2 ab^{-1} (top left), 10 ab^{-1} (top right) 75 ab^{-1} (bottom left) and 200 ab^{-1} (bottom right). We assume that the result is consistent with the Standard Model.

necessarily share this suppression which can be enhanced by an order of magnitude or more. The best current limit is $BR(B_s \rightarrow \mu^+\mu^-) < 4.3 \times 10^{-8}$ at 95% C.L. obtained by CDF [37]. The recent result from LHCb obtained using about 50 pb^{-1} gives already a very competitive limit: $BR(B_s \rightarrow \mu^+\mu^-) < 5.6 \times 10^{-8}$ at 95% C.L. [38]. $B_s \rightarrow \mu^+\mu^-$ is in fact a golden mode for LHCb which can overtake the sensitivity of CDF with about 100 pb^{-1} and reach a precision of about 20% with the full dataset of 10 fb^{-1} . Further improvement requires the control of the B_s production rate or the precise measurement of some reference B_s absolute BR . The latter could be provided by a run of a super flavor factory at the $\Upsilon(5S)$ resonance. It is worth mentioning that, while the LHCb measurement of $BR(B_s \rightarrow \mu^+\mu^-)$ will seriously challenge the large $\tan\beta$ scenario, it cannot be excluded that large $\tan\beta$ effects show up in $B \rightarrow \ell\nu$ and not in $B_s \rightarrow \mu^+\mu^-$.

4.3.4 Semileptonic Decays

The improvement of the measurement of the magnitude of the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ can be only achieved at super flavor factories. In a landscape where γ will be already measured with a good precision at LHCb, the determination of $|V_{cb}|$ and $|V_{ub}|$ is the key ingredient to precisely obtain the UT parameters $\bar{\rho}$ and $\bar{\eta}$ in the presence of NP. Two approaches are possible using inclusive and exclusive decays. The current precision for $|V_{ub}|$ using both approaches is about 10%. For the inclusive decays the use of a large sample of data allow to use the most clean analysis approaches (hadronic recoil tag) which have been already tested in the present B -factory. Recent studies have shown that an experimental error at about (2-3)% can be reached. How to improve the theoretical uncertainty on the inclusive $|V_{ub}|$ determination at the percent level is an open issue. If we assume that, in the super flavor factory era, this uncertainty will be dominated by the knowledge of the b quark mass, a total error at about 3% on $|V_{ub}|$ seems possible [7]. On the other hand, the measurement of $|V_{ub}|$ using exclusive decays is presently limited by theoretical uncertainties on the form factors (about 10%). Lattice calculations are expected to significantly improve to approximately 2-3% in the case of the most promising decay $B \rightarrow \pi\ell\nu$ [5, 9]. From the experimental side, the use of the recoil tag technique will allow to keep the total error at about 3%. The two methods uses independent data sample and theory uncertainties, thus an error on $|V_{ub}|$ below 2% could be possible. Similarly $|V_{cb}|$ can be determined with both methods with a precision below the percent level [9].

4.4 Charm Physics

Charm physics could play an important role in the NP searches. In fact, among the up-type quarks, only charm allows to probe FCNC (and thus NP) in oscillation phenomena and in particular those involving CP violation. Note that, in the SM, direct CP violation in charm transitions only occurs in Cabibbo-suppressed modes at an observable level $\sim \mathcal{O}(10^{-3})$ and time dependent CP asymmetries could reach the 10^{-5} [10^{-4}] level in Cabibbo-allowed and singly[doubly]-suppressed modes. The recent

observation of $D-\bar{D}$ oscillations, with $x_D, y_D \simeq 0.005-0.01$, has clearly open the possibility of observing CP violation which would be a clear manifestation of NP.

Super flavor factories can perform studies on the charm sector in a comprehensive manner, with a large data sample in the $\Upsilon(4S)$ region. SuperB can also run the $\psi(3770)$ resonance. In fact the SuperB collider is designed to run at lower center-of-mass energies and reduced luminosity. In addition, the option to have a boost sufficient to perform time-dependent measurements is under study. With very short low-energy runs, a data sample an order of magnitude larger than the final BES-III sample can be readily obtained. Running at the charm threshold should allow to measure precisely the D decay form factors with semileptonic decays and the D decay constant with leptonic decays. These measurements would provide important benchmarks for lattice QCD calculations. In addition, Dalitz analyses with high statistics would provide inputs to the measurement of the UT angle γ . Finally, a run at the charm threshold could also be helpful for FCNC searches.

4.5 τ Physics

4.5.1 Lepton Flavor Violation

Lepton Flavor Violation (LFV) in τ decays is one of the most powerful probe of NP. This search at super flavor factories is complementary with the existing and future neutrino experiments aiming at measuring θ_{13} and with the MEG experiment at PSI searching for $\mu \rightarrow e\gamma$. With an integrated luminosity of 75 ab^{-1} , SuperB can gain an order of magnitude on several LFV in τ decays (see Table 2), exploring a significant portion of the parameter space of various NP scenarios.

Final State	Sensitivity [10^{-10}]	Final State	Sensitivity [10^{-10}]
$\mu\gamma$	20	$\mu\eta$	4
$e\gamma$	20	$e\eta$	6
3μ	2	ℓK_S^0	2
$3e$	2		

Table 2: The experimental sensitivities (in units of 10^{-10}) expected for LFV searches in τ decay with a dataset of 75 ab^{-1} .

Super flavor factories are unique facilities for these studies. LHCb can contribute only to the 3μ channels with an estimated sensitivity smaller by about one order of magnitude.

A longitudinally-polarized electron beam (at the level of about 85%) can be obtained at SuperB and helps to study the structure of LFV couplings in τ decays. Recent analyses have shown that polarization gives new handles to discriminate between signal and background and thus probably allows to push even further the sensitivity of LFV measurements. Polarization is also important to search for τ EDM, $(g-2)_\tau$ and CP violation in τ decay.

4.6 K Physics

The main issue of the Kaon physics in the next decade is the study of rare decays. The actors will be NA62 K^+ -factory at CERN (and possibly P996 at Fermilab), KOTO K_L -factory at J-Park, KLOE-2 K_S -factory at Frascati.

NA62 is approved and will start to take data at CERN in 2013 with the aim of collecting about 100 events $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ using the in-flight technique. This would allow to reach a precision of 10% on the determination of the $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$. P996 at Fermilab could be constructed before 2020 and using the stopped-kaon technique will be able to reconstruct about 200 events. KOTO experiment at J-PARC aims at reaching a single event sensitivity at the level of the SM expectation in three years running for the ultra rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$.

For what concern the K_S rare decays, KLOE-2 experiment, restarting in 2011, aims at pushing down to 1% the error on $K_S \rightarrow \gamma\gamma$ and at observing few $K_S \rightarrow \pi^0 \ell \ell$ events with the full dataset of 20 fb^{-1} .

It is worthwhile recalling that NA62 and KLOE-2 can render the test on lepton universality violation more stringent (few per mill) in the near future by studying the ratio between $K^+ \rightarrow e^+ \nu$ and $K^+ \rightarrow \mu^+ \nu$. To reach the per-mill precision, however, next-generation experiments such as P36 at J-PARC are needed. Finally KLOE-2 and NA62 can contribute in the searches for new light neutral boson associated with spontaneously broken global symmetries by studying events like $K^+ \rightarrow \pi^+ X^0$.

4.7 Other Opportunities

4.7.1 Spectroscopy and direct searches

The recent results from the B -factories provide evidence for the renaissance of hadronic spectroscopy. Although past performances provide no guarantee of future success, new particles have been discovered by the B -factories at a rate of more than one per year, and there is no reason to believe that this should not continue into the multi-ab⁻¹ territory. Super flavor factories will open a unique window on this physics as they allow for a high statistics study in a clean e^+e^- environment, ideal for the complicated analyses necessary to pin down the nature of these new hadrons. Particles can be searched for in exclusive decays, or by using inclusive techniques, such as the recoil analysis. The possibility of running at different center-of-mass energies (as at $\Upsilon(3S)$) extends the reach of this branch of the physics programme.

The studies of lower Υ resonances would allow testing extensions of the Standard Model in a manner complementary to the physics program studied at previous B -factories and at the LHC. Among the possibilities, we mention the search for a light pseudo-scalar Higgs boson produced in the decay $\Upsilon(nS) \rightarrow \ell\ell\gamma$ ($n = 1, 2, 3$) as an intermediate state occurring in models like the NMSSM [39]. In addition, the study of the decays $\Upsilon(nS)$ to invisible allows to obtain independent constraints on models with light dark matter [40].

4.7.2 Electroweak neutral current measurements

With polarization, SuperB can measure the left-right asymmetry of $e^+e^- \rightarrow \mu^+\mu^-$ repeating at a lower energy the measurement performed by the SLC collaboration at the Z -pole [41, 42] SLC measured $\sin^2 \theta_W = 0.23098 \pm 0.00026$. An important contribution to the error comes from systematic component of ± 0.00013 , dominated by the polarization uncertainty of 0.5%. A feasibility study has been performed assuming a left-right asymmetry of -0.0005 . With 75 ab⁻¹ and 80% polarization, the statistical error on the left-right asymmetry will be about 5×10^{-6} (a $\mathcal{O}(1\%)$ relative error). If the polarimeter systematic errors can be kept below this level, the uncertainty on $\sin^2 \theta_W$ will be ~ 0.0002 , which is competitive with the SLC measurement. Similar measurements can be made with $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$ and with charm. In this case the larger errors are expected because of the lower selection efficiency.

These precision measurements are sensitive to the same new physics scenarios, such as a Z' , being probed by the QWeak experiment at the Jefferson Laboratory, which will measure $\sin^2 \theta_W$ to approximately 0.3% at $Q^2 = (0.16 \text{ GeV})^2$. SuperB will provide a point at $Q^2 = (10.58 \text{ GeV})^2$ with an error comparable to that of the measurement at the Z -pole.

5 Beyond The Standard Model With Precision Flavor Physics

In this section we illustrate the impact of future flavor measurements on a selection of NP models, profiting from the studies of refs. [5, 8, 9]. Of course, the conclusions one can draw from this exercise are strongly influenced by the status of particle physics at the time these measurements are actually performed. The framework for next-generation flavor physics is being set by present experiments both in the flavor sector and at high- p_T . NP signals in the near future are certainly possible and eagerly awaited. Meanwhile, for the sake of illustration, we consider various NP models in different scenarios to show the role of precision flavor physics in elucidating the structure of physics beyond the SM.

None of the considered models will be presented in detail. We restrict our presentation to what is needed for our purpose and refer the reader to the original literature for any additional information.

5.1 Precision CKM Matrix

Next-generation flavor experiments are expected to increase the precision of the determination of SM flavor parameters by one order of magnitude. This is a first step in the quest for NP. Indeed, the high-correlated SM scenario, represented by the overlapping of several CP-conserving and CP-violating constraints in the UT analysis, can easily break down in the presence of new flavor structures. Figure 5 illustrates a conceivable scenarios at the end of next-generation flavor experiments: some of the improved experimental constraints of the UT no longer overlap signaling the presence of source of flavor- and CP-violation beyond the CKM matrix. The generalized UT analysis, exploiting the high-precision tree-level constraints, $|V_{ub}/V_{cb}|$ and γ , can still determine the CKM parameters and, in addition, point out the amplitudes deviating from the SM [44].

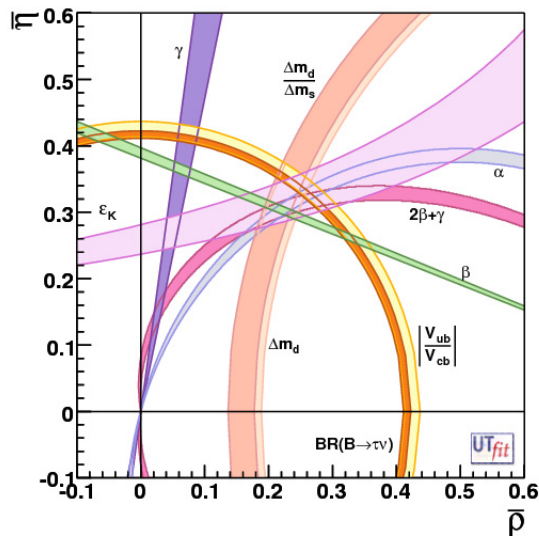


Figure 5: Extrapolation of the UT fit using the precisions expected at the next-generation flavor facilities. Central values of all constraints are kept at the present averages.

On the other hand, it could happen that the improved UT experimental constraints continue to overlap in one point. This would imply that NP is not showing up in these constraints, mainly coming from mixing amplitudes, even with the increased accuracy. Nonetheless the determination of the CKM parameters would still be improved resulting in a better knowledge of the SM contribution to other FCNC and CP violating processes and increasing in this way their sensitivity to NP. For example, the error on the SM prediction of a golden mode for NP searches in kaon physics, the CP-violating decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$, is presently dominated by the uncertainty of the CKM parameters [45].

It is worth mentioning that the UT fit extrapolation shown above requires an improved theoretical control of the hadronic uncertainty. Lattice QCD seems able to reach the required accuracy on the time scale of future experiments [5, 9]. Data-drive methods, based on the heavy quark expansion or on flavor symmetries, are also promising.

5.2 Supersymmetric Models

The Minimal Supersymmetric Standard Model (MSSM) is the supersymmetric extension of the SM with N=1 supersymmetry (SUSY), minimal particle content and R-parity conservation. The particle spectrum is doubled by the inclusion of supersymmetric partners and the Higgs sector is extended to include a second weak doublet (for a primer on the MSSM see for instance ref. [46]). While addressing most of the SM problems, the MSSM does not contain an explanation for supersymmetry breaking and

for flavor and CP violation. The two problems are intertwined, as most of the new sources of flavor and CP violation are located in the soft SUSY breaking terms. These terms are added to the MSSM Lagrangian to parameterized SUSY breaking in the most general way which does not spoil the natural stabilization of the weak scale and is compatible with gauge invariance and R-parity conservation.

The MSSM introduces 105 new parameters in addition of 18 in the SM, 97 of which are related to flavor and CP violation: 21 squark and slepton masses, 36 new mixing angles and 40 new CP-violating phases measurable in sfermion interactions [47]. Given this plethora of free parameters in the flavor sector, it is not surprising that the MSSM suffers from the NP flavor problem, namely it generates too large FCNC and CP violation for new particle masses at the TeV scale and $\mathcal{O}(1)$ flavor parameters.

If SUSY is found by high- p_T experiments at the LHC, establishing the flavor structure of the MSSM is a major goal achievable at current and next-generation flavor experiments with the added value of giving information on the SUSY breaking mechanism. If, conversely, SUSY particles are too heavy to be produced at the LHC, there are still chances to observe deviations from the SM in flavor physics. These two options are demonstrated in fig. 6 using the Mass Insertion (MI) approximation [48]

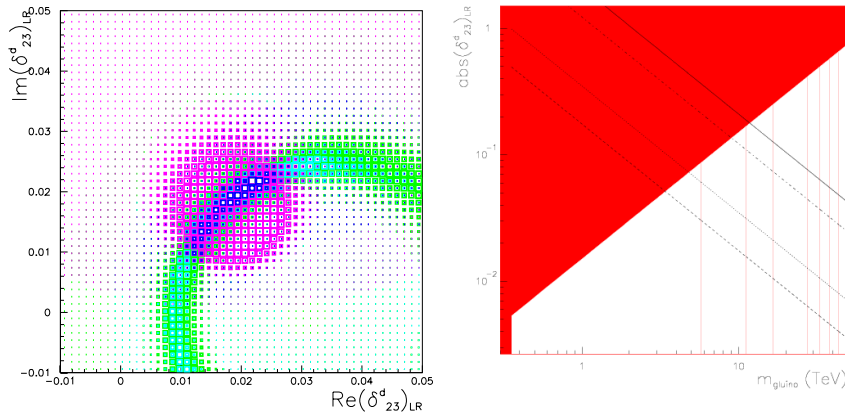


Figure 6: Left plot: extraction of $(\delta_{23}^d)_{LR}$ from the measurements of $a_{CP}(B_d \rightarrow X_s \gamma)$ (magenta), $BR(B_d \rightarrow X_s \gamma)$ (green) and $BR(B_d \rightarrow X_s \ell^+ \ell^-)$ (cyan) with the errors expected at next-generation flavor experiments. Central values are generated using $(\delta_{23}^d)_{LR} = 0.028 e^{i\pi/4}$ and squark and gluino masses at 1 TeV. Right plot: region of the parameter space where a non-vanishing $(\delta_{23}^d)_{LR}$ can be extracted with at least 3σ significance (in red).

to parameterize flavor-changing and CP-violating effects in the squark sector and considering for simplicity only dominant gluino contributions. The plot on the left shows the reconstruction of the MI $(\delta_{23}^d)_{LR}$ from the measurements of $A_{CP}(B_d \rightarrow X_s \gamma)$, $BR(B_d \rightarrow X_s \gamma)$ and $BR(B_d \rightarrow X_s \ell^+ \ell^-)$ with the errors expected at next-generation experiments. Central values are generated using $(\delta_{23}^d)_{LR} = 0.028 e^{i\pi/4}$ and squark and gluino masses at 1 TeV. Both modulus and phase can be reconstructed with more than 5σ significance. The plot on the right shows in red the region where a non-vanishing absolute value of the MI can be extracted from the data with a significance exceeding 3σ as a function of the gluino/squark mass. For masses around 1 TeV, one can measure MIs as small as 10^{-2} . On the other hand, for larger MIs, NP effects could be revealed for SUSY masses up to 10 TeV.

5.2.1 SUSY-breaking Scenarios

SUSY-breaking models provide a complementary way to present the MSSM flavor phenomenology and study the impact of next-generation experiments. Instead of a general parameterization of the MSSM soft SUSY-breaking terms, one consider a SUSY-breaking mechanism, theoretically or phenomenologically motivated, which reduces the number of independent parameters. As most of the SUSY-breaking terms are also flavor-violating parameters, a correlation pattern among flavor observables usually emerges, providing clues of the underlying theory. As look-alikes are clearly possible, this

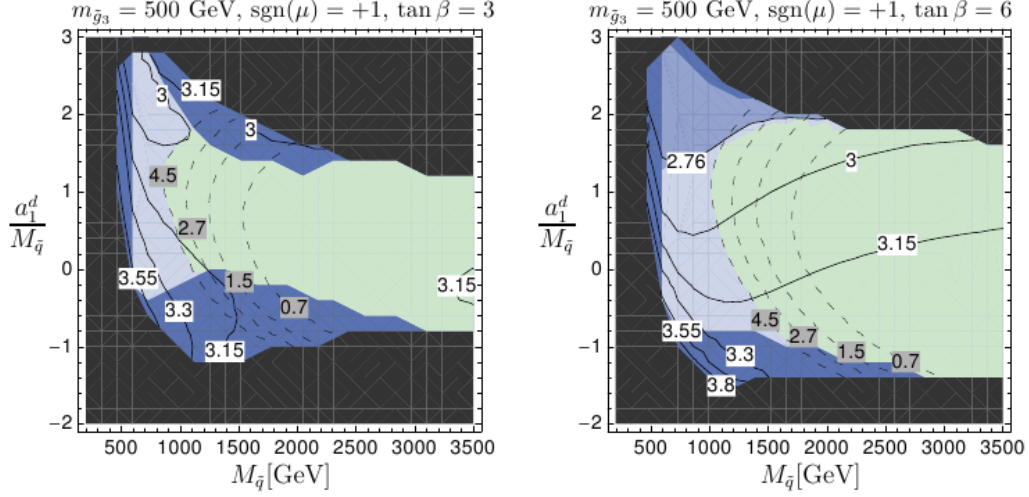


Figure 7: Bounds on the parameter space of the $SO(10)$ SUSY model considered in ref. [50] for $m_{\tilde{g}_3} = 500$ GeV and $\text{sgn}(\mu) = +1$ with $\tan \beta = 3$ (left) and $\tan \beta = 6$ (right). $BR(B \rightarrow X_s \gamma) \times 10^4$ solid lines with white labels; $BR(\tau \rightarrow \mu \gamma) \times 10^8$ dashed lines with gray labels. For more details, see ref. [50].

way of studying the NP flavor structure and the SUSY-breaking mechanism needs the measurement of several NP-sensitive observables. In this respect, super flavor factories are ideal experimental facilities.

To illustrate this approach, we report the results of the study in ref. [49] summarized by table 3. Several flavor observables are considered in a selection of SUSY models representative of different scenarios. SUSY contributions to these observables are classified as large, visible and small producing patterns which help identifying the model.

Table 3: “DNA” of flavor physics effects for the most interesting observables in a selection of SUSY models from ref. [49]. $\star\star\star$ signals large effects, $\star\star$ visible but small effects and \star implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM
$D^0 - \bar{D}^0$	$\star\star\star$	\star	\star	\star	\star
$S_{\psi\phi}$	$\star\star\star$	$\star\star\star$	$\star\star\star$	\star	\star
$S_{\phi K_S}$	$\star\star\star$	$\star\star$	\star	$\star\star\star$	$\star\star\star$
$A_{CP}(B \rightarrow X_s \gamma)$	\star	\star	\star	$\star\star\star$	$\star\star\star$
$A_{7,8}(B \rightarrow K^* \mu^+ \mu^-)$	\star	\star	\star	$\star\star\star$	$\star\star\star$
$A_9(B \rightarrow K^* \mu^+ \mu^-)$	\star	\star	\star	\star	\star
$B \rightarrow K^{(*)} \nu \bar{\nu}$	\star	\star	\star	\star	\star
$B_s \rightarrow \mu^+ \mu^-$	$\star\star\star$	$\star\star\star$	$\star\star\star$	$\star\star\star$	$\star\star\star$
$\tau \rightarrow \mu \gamma$	$\star\star\star$	$\star\star\star$	\star	$\star\star\star$	$\star\star\star$

Another example is given in ref. [8] where a large number of correlations between pairs of flavor observables is presented.

5.2.2 Grand-Unified Models

While in the SM the three gauge coupling constants do not exactly unify at any scale, grand-unification can occur with SUSY. Typical SUSY-GUTs are based on groups $SU(5)$ or $SO(10)$ breaking down to the SM group in one or more steps. As far as flavor is concerned, the distinctive feature of grand-unified models is that quark and leptons sit in the same representations of the gauge group resulting in an interesting interplay between quark and lepton flavor violation, the details of which are model dependent.

For example, many correlation plots are presented in ref. [8] for few grand-unified $SU(5)$ models including non-trivial correlations between $\tau \rightarrow \mu$ and $b \rightarrow s$ transitions.

Similarly, quark and lepton flavor-changing transitions between the second and the third generations put bounds on the parameter space of the $SO(10)$ model considered in ref. [50], as shown in fig. 7. In particular, the most effective constraint is the branching ratio of $\tau \rightarrow \mu\gamma$, which will be measured at the super flavor factories with a sensitivity of few in 10^{-9} .

More generally, next generation flavor experiments, measuring both quark and lepton flavor-changing processes, are a good testing ground for grand-unified SUSY models.

5.2.3 Minimal Flavor Violation

Minimal Flavor Violation (MFV) provides a solution to the NP flavor problem [51, 52, 53]. The basic assumption of MFV is that NP flavor effects are governed by the SM Yukawa couplings. MFV can be nicely formulated in the effective field theory language: taking the Yukawa couplings as spurions of the SM flavor group G_{flavor} in eq. (4), one can write G_{flavor} -invariant NP flavor-changing operators [52]. These allow to prove that a NP scale at the TeV is compatible with present flavor data in generic MFV models. Popular SUSY models like mSUGRA are MFV models. They are used as benchmarks for LHC physics as they have a reduced parameter space. Yet, by construction, MFV models produce small flavor effects (see for example ref. [54]) which could be hard to reveal even at next-generation experiments, with $BR(B \rightarrow X_s\gamma)$ being the most promising channel [7]. There are however two cases where even MFV models can give raise to large flavor effects: the large $\tan\beta$ regime in models with two Higgs doublets and the presence of non-negligible NP flavor-conserving phases, which are not forbidden by the MFV condition. In the former case, measurable deviations from the SM are expected to appear in $BR(B_s \rightarrow \mu^+\mu^-)$ and in $BR(B_d \rightarrow \tau\nu)$. Indeed, the large $\tan\beta$ scenario is already constrained by these branching ratios [55] and greatly improved measurements are expected from LHCb and the super flavor factories. In the latter case, flavor-diagonal phases can generate new CP-violating FCNC through loop effects. For example, a sizable non-standard $A_{\text{CP}}(B \rightarrow X_s\gamma)$ can be obtained in flavor-blind MSSM (FBMSSM) considered in ref. [56]. Clearly, as the sources of CP violation are flavor-conserving phases, the bounds coming from Electric Dipole Moments (EDMs) are important and should be taken carefully into account. Analogous results are obtained in the effective MFV model of ref. [57], which is based on a different flavor group, but produce a pattern of flavor-violating couplings similar to MFV.

In summary, the main motivation for MFV is keeping the NP scale at the TeV implying that new particles will be produced at the LHC. In such a case, the next-generation flavor experiments will have the task to study their flavor properties, trying to elucidate the pattern of flavor suppression. In this respect, establishing the MFV nature of NP could be a very hard task, involving small and correlated NP effects in K , B_d and B_s physics. On the other hand, even MFV models could produce large flavor effects in special regimes and super flavor factories will be able to perform key precision measurements to reveal them.

5.3 Standard Model With Four Generations

The interest in SM4, namely the extension of the SM which includes a fourth generation of heavy quarks and leptons, was revived in recent years [58, 59, 60]. While leaving several SM problems unresolved, SM4 has some interesting features: it allows for a heavier Higgs boson, relaxing the indication of a light Higgs coming from the fit of electroweak precision data, and can accommodate a large CP violation in B_s mixing, as hinted by recent Tevatron data. In addition, the new fermions can be produced and detected at the LHC, so that SM4 will be found or excluded soon. In the former case, besides the direct observation, measurable NP flavor effects are expected in time-dependent angular analysis of $B_s \rightarrow J/\psi\phi$, precisely measured at LHCb. Corresponding deviations from the SM in $b \rightarrow s$ transitions involving the B_d meson can be measured at the super flavor-factories, as shown in fig. 9.

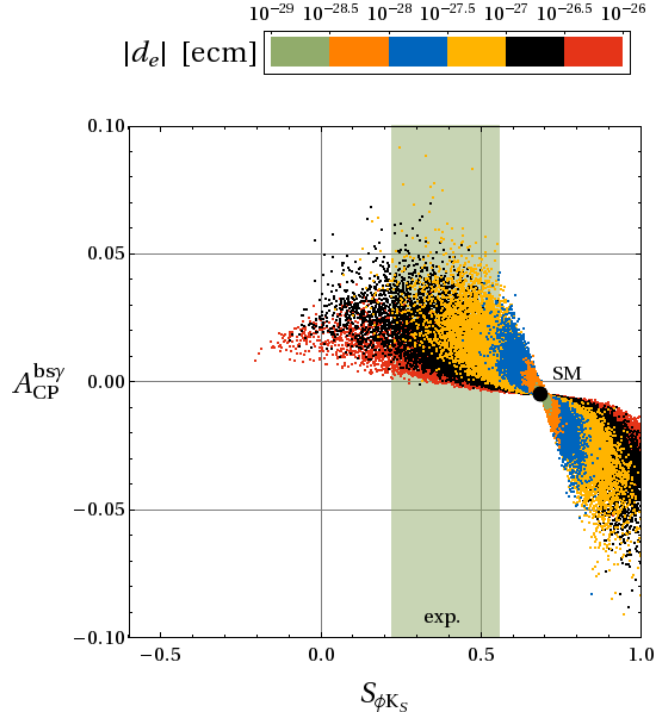


Figure 8: Correlation between the CP asymmetries $A_{\text{CP}}(B \rightarrow X_s \gamma)$ and $S_{B_d \rightarrow \phi K_S}$ in the FBMSSM [56]. The various colors indicate the predicted lower bound on the electron EDM $|d_e|$.

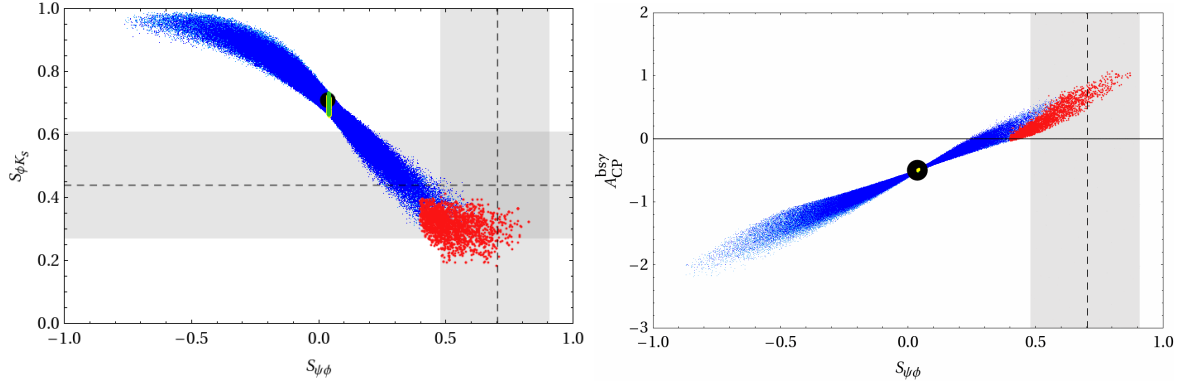


Figure 9: Correlation of $S_{\psi\phi}$ with $S_{\phi K_S}$ (left) and $a_{\text{CP}}(b \rightarrow s \gamma)$ (right) in the SM4 from ref. [60].

5.4 Little Higgs Models

Little Higgs models assume that the Higgs field is a pseudo-Goldstone boson associated to the breaking of a global symmetry [61]. The careful choice of the breaking mechanism can naturally stabilize the electroweak scale, raising the cutoff of the theory up to 10 TeV region. While several variants of little Higgs models exist, the Littlest Higgs model with T-parity (LHT) has the additional features of fulfilling the constraints coming from electroweak precision data for a relatively small symmetry breaking scale f and providing a dark matter candidate. In this model, the exchange of new heavy quark, scalars and gauge bosons gives rise to new flavor effects. FCNC and CP violation in the LHT have been extensively studied in refs [62, 63]: large effects are possible in rare kaon decays, such as $K_L \rightarrow \pi^0 \nu \bar{\nu}$ and $K \rightarrow \pi^+ \nu \bar{\nu}$ and $B_s - \bar{B}_s$ mixing, while B_d processes typically receive small corrections.

Lepton flavor violation in τ decays is particularly interesting in LHT. Contrary to the SM and many of its extensions including the MSSM, the ratio of $BR(\tau \rightarrow 3\mu)$ over $BR(\tau \rightarrow \mu\gamma)$ is not governed by the electromagnetic constant α_e , see table 4. The rate of $\tau \rightarrow \mu\gamma$ can be large enough to be measured at super flavor factories if the symmetry breaking scale f is around 500 GeV. For larger

Table 4: Comparison of various ratios of branching ratios in the LHT model ($f = 1$ TeV) [63] and in the MSSM without [64] and with [65] significant Higgs contributions.

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{BR(\tau^- \rightarrow e^- e^+ e^-)}{BR(\tau^- \rightarrow e \gamma)}$	0.04...0.4	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{BR(\tau^- \rightarrow \mu^- \mu^+ \mu^-)}{BR(\tau^- \rightarrow \mu \gamma)}$	0.04...0.4	$\sim 2 \cdot 10^{-3}$	0.06...0.1
$\frac{BR(\tau^- \rightarrow e^- \mu^+ \mu^-)}{BR(\tau^- \rightarrow e \gamma)}$	0.04...0.3	$\sim 2 \cdot 10^{-3}$	0.02...0.04
$\frac{BR(\tau^- \rightarrow \mu^- e^+ e^-)}{BR(\tau^- \rightarrow \mu \gamma)}$	0.04...0.3	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{BR(\tau^- \rightarrow e^- e^+ e^-)}{BR(\tau^- \rightarrow e \mu^+ \mu^-)}$	0.8...2.0	~ 5	0.3...0.5
$\frac{BR(\tau^- \rightarrow \mu^- \mu^+ \mu^-)}{BR(\tau^- \rightarrow \mu^- e^+ e^-)}$	0.7...1.6	~ 0.2	5...10

scales, $BR(\tau \rightarrow \mu \gamma)$ becomes too small, but $BR(\tau \rightarrow 3\mu)$ could still be measurable. In any case the large ratio $BR(\tau \rightarrow 3\mu)/BR(\tau \rightarrow \mu \gamma)$ is a distinctive feature which could tell the LHT apart from other extensions of the SM.

Table 5: Maximal values on LFV τ decay branching ratios in the LHT model, for two different values of the scale f , after imposing the constraints on $\mu \rightarrow e \gamma$ and $\mu^- \rightarrow e^- e^+ e^-$ from ref. [63].

decay	$f = 1000$ GeV	$f = 500$ GeV	SuperB sensitivity
$\tau \rightarrow e \gamma$	$8 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
$\tau \rightarrow \mu \gamma$	$8 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
$\tau^- \rightarrow e^- e^+ e^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
$\tau^- \rightarrow \mu^- \mu^+ \mu^-$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
$\tau \rightarrow \mu \eta$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$4 \cdot 10^{-10}$
$\tau \rightarrow e \eta$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$6 \cdot 10^{-10}$

LHT effects in D physics have been studied in ref. [66]. A large CP violation, a clear NP signal, can be present both in the mixing amplitude (A_{SL}) and in the time-dependent CP asymmetry of $D \rightarrow K_S \phi$ ($S_{K_S \phi}$). The possibility to measure D time-dependent CP asymmetries is under study at SuperB.

5.5 Warped Extra Dimensions

Randall-Sundrum models of extra dimensions exploits the geometry of the fifth dimension to naturally stabilize the Fermi scale [67]. In addition, by putting fermions in the bulk, one can address the SM flavor problem: the hierarchies in quark masses and mixings are obtained from the localization of fermions along the fifth dimension [68].

New flavor effects in these models arise from the exchange of Kaluza-Klein excitations. They depend crucially on the specific realization of the model, although in general they are severely constrained by CP violation in $K-\bar{K}$ mixing. In the minimal scenario with only the SM gauge group in the bulk, one finds that large effects are possible in both B and K decays [69, 70, 71], see for example the correlation between $BR(B_s \rightarrow \mu^+ \mu^-)$ and $BR(B \rightarrow X_s \nu \bar{\nu})$ in fig. 10. The former BR will be measured soon at LHCb, while the transition $b \rightarrow s \nu \bar{\nu}$ can be measured in the exclusive decays $B \rightarrow K^* \nu \bar{\nu}$ with full statistics at SuperB.

Other realizations, such as the custodially-extended bulk gauge symmetry, suppress the NP contributions to B FCNCs, although large effects in kaons and in $B_s-\bar{B}_s$ mixing are still possible [70].

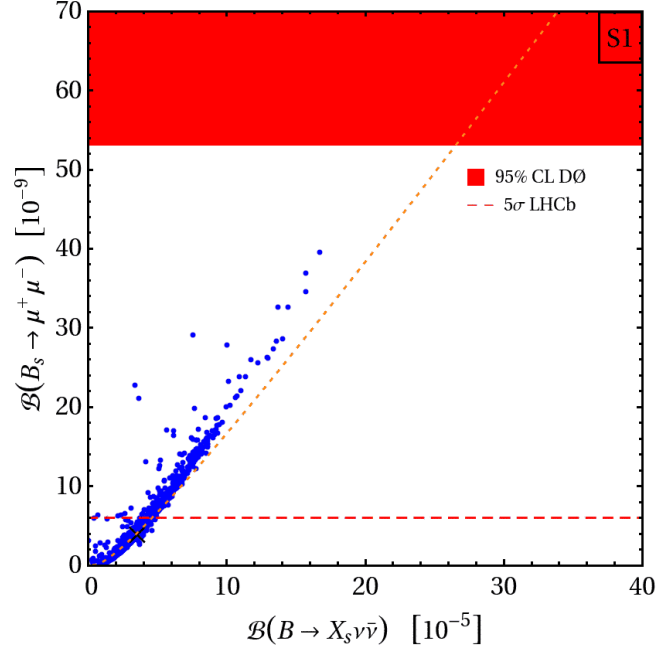


Figure 10: Correlation between the branching ratios for $B_s \rightarrow \mu^+ \mu^-$ and $B \rightarrow X_s \nu \bar{\nu}$ in the minimal RS model from ref. [71].

6 Conclusions

In this review we have considered a large subset of flavor measurements, briefly discussing their present status and the expected sensitivities at next-generation experiments, including possible systematic or theoretical limitations. We have then presented some examples of flavor effects generated in a selection of NP models which could be measurable in the future. In particular, we selected those correlations among observables which could provide a distinctive mark of the NP model, showing how flavor physics could help telling it apart from the others.

The next decade will be crucial for the future of particle physics in general and of collider physics in particular. The LHC already started looking for the Higgs boson and for new particles at the TeV scale. In this context, flavor physics could have a prominent role in characterizing a TeV NP and looking for signals from the multi-TeV region. It is even possible that the first evidence for NP come from flavor, with LHCb measuring NP-sensitive channels like $B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\phi$. In any case, reconstructing the NP Lagrangian from the data is a collective effort requiring the interplay of both direct and indirect searches, together with an accurate theoretical control of the SM contributions. Improved experimental results at the energy and intensity frontiers and the most advanced theoretical techniques are therefore required ingredients to go steadily beyond the SM.

Precision flavor physics can certainly give a major contribution to this effort. Next-generation experiments will offer new opportunities by pushing existing flavor measurements to an unprecedented accuracy and by opening the possibility to measure new NP-sensitive observables in all flavor sectors.

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